LA-UR-01-5615
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THE SPLIT-HOPKINSON PRESSURE BAR: AN EVOLVING QUANTIFICATION TOOL AND TECHNIQUE FOR CONSTITUTIVE MODEL VALIDATION

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ABSTRACT - This talk will review the status of the split-Hopkinson Pressure Bar (SHPB) as an experimental tool and highlight recent innovations in the utilization of this apparatus to characterize the dynamic response of "soft" polymeric and polymeric-based composite materials as well as materials loaded in more complex stress states. The use of the SHPB as a means to validate constitutive strength models is described.

INTRODUCTION: Following the original split-Hopkinson pressure bar (SHPB) or Kolsky-bar apparatus developed to measure the compressive mechanical behavior of a material(Gray III [2000]), alternate pressure bar testing schemes have been designed over the past five decades to load samples in a broad range of stress states to address a variety of high-strain-rate loading applications. Pressure-bar derived techniques allow measurement of the stress-strain mechanical response of a material in the strain rate regime, strain rate > 200 s^{-1}, by employing projectile driven impacts to directly or indirectly induce stress wave propagation in a sample. The split-Hopkinson pressure bar or Kolsky bar is capable of achieving the highest uniform uniaxial stress loading of a specimen in compression at nominally constant strain rates of the order of 10^3 s^{-1} (Gray III [2000]). Hopkinson-bar techniques have also been developed to probe the high-rate response of materials in tension and torsion as well as mixed-mode stress states. In this review the status and innovations which have occurred germane to the SHPB over the past few years are highlighted. Finite-element modeling (FEM) of the SHPB is also discussed as a robust means to validate constitutive strength models.

PROCEDURES, RESULTS AND DISCUSSION:

The Split-Hopkinson pressure bar technique is named for Bertram Hopkinson who, in 1914, used the induced wave propagation in a long-elastic-metallic bar to measure the pressures produced during dynamic events not strains(Gray III [2000]). Based on this seminal work, the experimental apparatus utilizing elastic stress-wave propagation in long rods to study dynamic processes in materials was named the Hopkinson Pressure Bar. Later work by Davies and Kolsky utilized two Hopkinson pressure bars in series, with a sample sandwiched in between the pressure bars, to quantify the dynamic stress-strain response of materials (Gray III [2000]). This technique thereafter has been referred to as either the split-Hopkinson pressure bar, Davies bar, or Kolsky bar(Gray III [2000]). The generalized SHPB technique in its current form owes a debt of gratitude to each of these innovative scientists and the researchers since that time responsible for the continued development of the SHPB and high-precision data acquisition equipment without which the reproducibility of this technique would not have been possible.

Following the original SHPB apparatus development, alternate Hopkinson bar schemes were designed for loading samples in uniaxial tension, torsion, and simultaneous torsion-compression(Gray III [2000]). Split-Hopkinson bars have also been utilized to load notched samples to measure either the shear strength or the fracture toughness of an impact-loaded material. The basic theory of how to reduce the pressure bar data based upon one-dimensional stress wave analysis remains common to all three uniaxial loading stress states. Of the different Hopkinson bar techniques, i.e., compression, tension, and torsion, the compression bar remains the most readily analyzed, least complex method to achieve a uniform high-rate stress state, and utilizes simple right-regular solid samples.

Recent innovations have utilized the SHPB to quantify the dynamic stress-strain response of complex composites(Ninan, et al. [2001]), visco-plastic materials (including polymeric and foams)(Li and Lambros [2001]), geologic materials(Frew, et al. [2001]), and as a means to validate the constitutive response of materials by coupling SHPB testing with detailed finite-element modeling of SHPB samples(Brara, et al. [2001, Burlion, et al. [2000]). Alternate stress-state loading in the SHPB has also been developed by researchers to probe complex loading states such as shear testing of sheet steel(Rusinek and Klepaczko [2001]) and studies to investigate high-speed sliding wear(Rajagopalan and Vikas [2001]) to name but a few recent examples.

A unifying theme common to a number of the recent research articles in the literature is the focus on attainment of a uniaxial state of stress(Frew, et al. [2001, Li and Lambros [2001]). These papers illustrate that to understand the uniaxial stress-state constitutive response of materials it is absolutely crucial to examine the different analyses used to calculate sample stress from the incident and reflected pressure bar strains during SHPB testing. This is particularly important for high-density metals, polymers, and metallic foams were inertial and stress-state equilibrium, respectively, can be problematic(Gray III and Blumenthal [2000]). In this review, the importance of utilizing 1 & 2-wave analyses to verify valid uniaxial stress-state pressure bar data is discussed and illustrated for a few metallic and polymeric materials including foams.

The establishment of physically-based constitutive models to describe complex loading processes requires a detailed knowledge of the singular and correlated effects of temperature and strain rate controlling the dynamic response of materials. The use of coupled finite-element modeling (FEM) with SHPB testing to validate constitutive response has seen increased emphasis within the last 5 years. FEM modeling has been shown to be an effective method to probe stress state equilibrium data, specimen constitutive behavior, and subsequent damage on “virtual” -vs- real specimens in the SHPB. Coupled constitutive and damage evolution modeling can also be realized in SHPB simulations(Burlion, et al. [2000]).

CONCLUSIONS: The split-Hopkinson Pressure Bar remains an active area of research and through continued innovations is being widely applied to the characterization of polymeric and polymeric materials, geologic materials, and the response of materials to alternate stress states. 3-D finite element simulations of SHPB experiments can effectively be utilized to validate the dynamic constitutive and damage evolution response of materials.

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